

1. Introduction:

The Aura satellite was launched on July 15, 2004 with four scientific instruments on board, including the Ozone Monitoring Instrument (OMI). OMI is a nadir viewing UV/VIS imaging spectrometer that measures ultraviolet and visible backscattered solar radiation for retrieval of tropospheric and stratospheric vertical columns of such gases as NO_2 , O_3 , SO_2 , BrO , HCHO and OCIO . Measurement uncertainties from satellite instruments require them to be properly validated. A Multifunction Differential Optical Absorption Spectrometer instrument (MFOAS), built for ground based validation of OMI, was first fielded in a prototype form during the INTEX B campaign at Pacific Northwest National Laboratory in Richland, WA, April 17 – May 17, 2006.

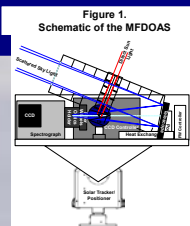
2. Objectives:

The objectives of this presentation are:

- Description of the MFOAS instrument
- Description of our INTEX B campaign participation
- Presentation of data analysis and NO_2 slant column results from INTEX B measurements
- Comparison of tropospheric NO_2 ASDC with in-situ CO measurements
- Preliminary comparison of NO_2 slant column results with OMI tropospheric NO_2 products
- Future work

3. MFOAS instrument description:

The MFOAS instrument observes scattered skylight with a 1° FOV at varying viewing azimuth and elevation angles as well as direct sun light in the uv-visible spectral region for determination of NO_2 , O_3 , SO_2 , and CH_2O slant columns. The MFOAS spectrograph is a single pass Czerny-Turner (Acton SP-2300i) spectrograph of focal length 300mm. The instrument covers a wavelength range from 305nm to 480nm, and has a spectral resolution of 0.82nm (6 pixels FWHM). Scattered sky light is collected by a 12cm telescope and passes into the spectrograph through two filter wheels which contain depolarizers, spectral flattening filters, and uv cutoff filters. Direct sun light is fed into a spectralon integrating sphere (diameter 8cm) before passing through the filter wheels.



A two-dimensional CCD detector (400×1340 pixels 2) is used in the focal plane. Spectrograph stray light is reduced by a spectral flattening filter which reduces the long wavelength throughput of the instrument. Tracking/positioning utilizes a Kipp & Zonen tracker which moves the entire instrument. An instrument schematic is presented in Figure 1.

4. INTEX B campaign

The Intercontinental Chemical Transport Experiment – Phase B (INTEX-B) took place from 17 April to 17 May 2006. The primary goal of the (mainly aircraft) campaign was to quantify the transpacific transport and evolution of Asian pollution to North America with the emphasis on validation of satellite observations of tropospheric composition. The ground-based MFOAS instrument was first fielded in a prototype form during this campaign for Aura/OMI validation. This presentation will focus on tropospheric NO_2 slant column results derived from the scattered skylight observations.

4a. Location

The MFOAS instrument was positioned on the roof of a building at Pacific Northwest National Laboratory, Richland, WA (latitude: 46.3409, longitude: -119.2787)



Richland is located in a semi-rural area known as Tri-Cities (merged cities of Kennewick, Pasco and Richland, WA) with total population of approximately 150,000 in an area of 250 km^2 . PNNL is situated north from the center of Richland (approximately 15 km) and north-west of the population center.

4b. Measurements

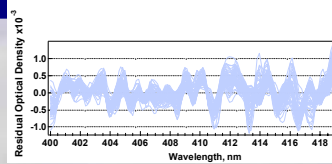
The MFOAS instrument operated mainly in scattered skylight mode (MAXDOAS). The observation sequence included elevation angles of 5° , 15° , 45° and zenith at each of azimuths north, south, east, and west. Direct sun observations were unfortunately not made reliably. The observation time at each azimuth/elevation position was about 1 min, with the spatial time resolution of about 25min per full scan.

5. Data Analysis

NO_2 slant columns were derived using the differential optical absorption spectroscopy (DOAS) technique. DOAS is based on the Beer – Lambert law, where σ' is a differential absorption cross section for molecule I' , and I'_0 is a modified I_0 .

$$\text{I}(\lambda) = \text{I}'_0(\lambda) \cdot e^{-\sum (\sigma'(\lambda) \cdot \text{Slant Column Density}_i)}$$

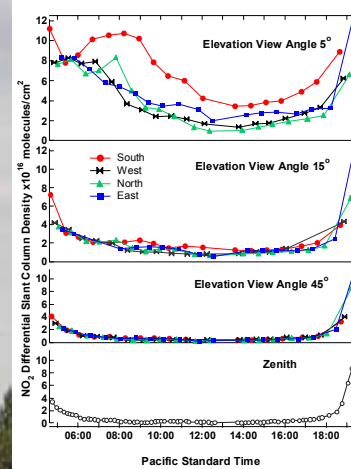
Vertical column retrieval from the multi-axis measurements requires application of spherical radiative transfer theory and is not addressed at this point. We will concentrate on derivation of slant columns. A nonlinear least squares algorithm was utilized to fit cross sections of NO_2 , O_3 , Ring, and instrument polarization in a small spectral region 400nm–419nm. A polynomial was also added to remove slowly varying Rayleigh and Mie Scattering. The reference spectrum used for data analysis (I_0 in Beer – Lambert Law) was taken at local noon zenith on April 30, 2006, an unpolluted day. Raw spectra were corrected for detector darks and flat field. Figure 2 shows residual optical densities after fitting procedure for observations taken on May 9, 2006 at 5-degree elevation and all directions.



6. NO_2 slant column results

Figure 3 presents the spatial and temporal variation of NO_2 differential slant column for May 9, 2006, a polluted day. Higher column densities were observed to the south and east towards the urban center. Measurements taken at 5-degree elevation showed higher NO_2 tropospheric column compared to 15 and 45-degree angles, as expected. These elevated NO_2 slant column densities were particularly pronounced during the morning rush hour.

Figure 3. MFOAS NO_2 Differential Slant Column: 9 May 2006



7. Comparison of tropospheric NO_2 SCD with CO in-situ measurements

To evaluate the ability of the MFOAS instrument to measure local pollution we compared CO mixing ratio taken at the PNNL site with the MFOAS derived differential NO_2 slant column densities. CO was chosen to represent local vehicular pollution. The NATIVE trailer produced in-situ measurements of O_3 , NO , NO_2 , CO , SO_2 , and meteorological conditions. Figures 4, 5, 6 show NO_2 differential SCD and CO mixing ratios for one unpolluted and two polluted days. Good correlation is observed between the temporal variations of both species from the NATIVE trailer and MFOAS. Differences can be generally attributed to the fact that CO measurements are point measurements north of the city center versus long path measurements from the MFOAS.

Figure 5. Comparison of NO_2 Tropospheric Δ SCD with CO In-Situ Measurements

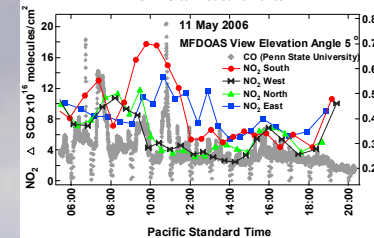
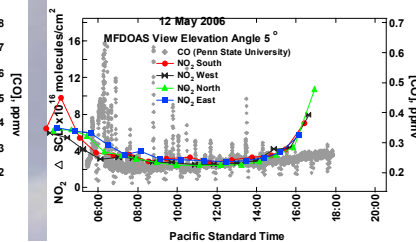


Figure 6. Comparison of NO_2 Tropospheric Δ SCD with CO In-Situ Measurements



8. Preliminary comparison of NO_2 differential slant column results with the OMI tropospheric NO_2

The Aura satellite flies over Tri-Cities area around 13:00hr with a spatial resolution of 13km x 24km. Figure 7 shows a contour plot of tropospheric NO_2 VCD for May 9, 2006. OMI tropospheric NO_2 vertical column densities "integrated" over several pixels in the MFOAS observation direction were compared to MFOAS differential NO_2 SCDs derived from 5-degree elevation sun observations. Figure 8 shows preliminary results for April 30 through May 13, 2006. Reasonable correlation between MFOAS measurements and OMI results is observed, however not for all days. Some of the discrepancies can be attributed to "integration" of OMI data along the MFOAS observation path. The comparison will become more quantitative when our slant column numbers can be replaced by vertical column abundances after application of a spherical radiation code.

Figure 7. OMI Tropospheric NO_2 Vertical Column Density: 9 May 2006

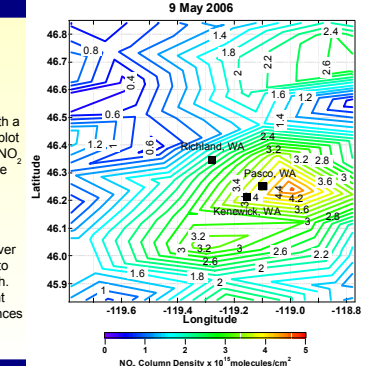


Figure 8. Comparison of OMI Tropospheric NO_2 Vertical Column with MFOAS NO_2 Differential Slant Column Density

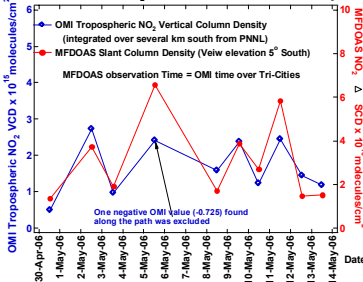
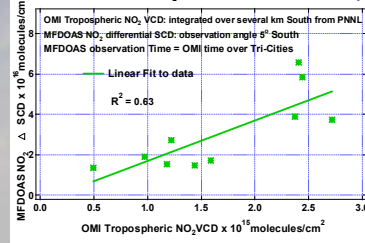


Figure 9. Correlation between OMI Tropospheric NO_2 Vertical Column and MFOAS NO_2 Differential Slant Column Density



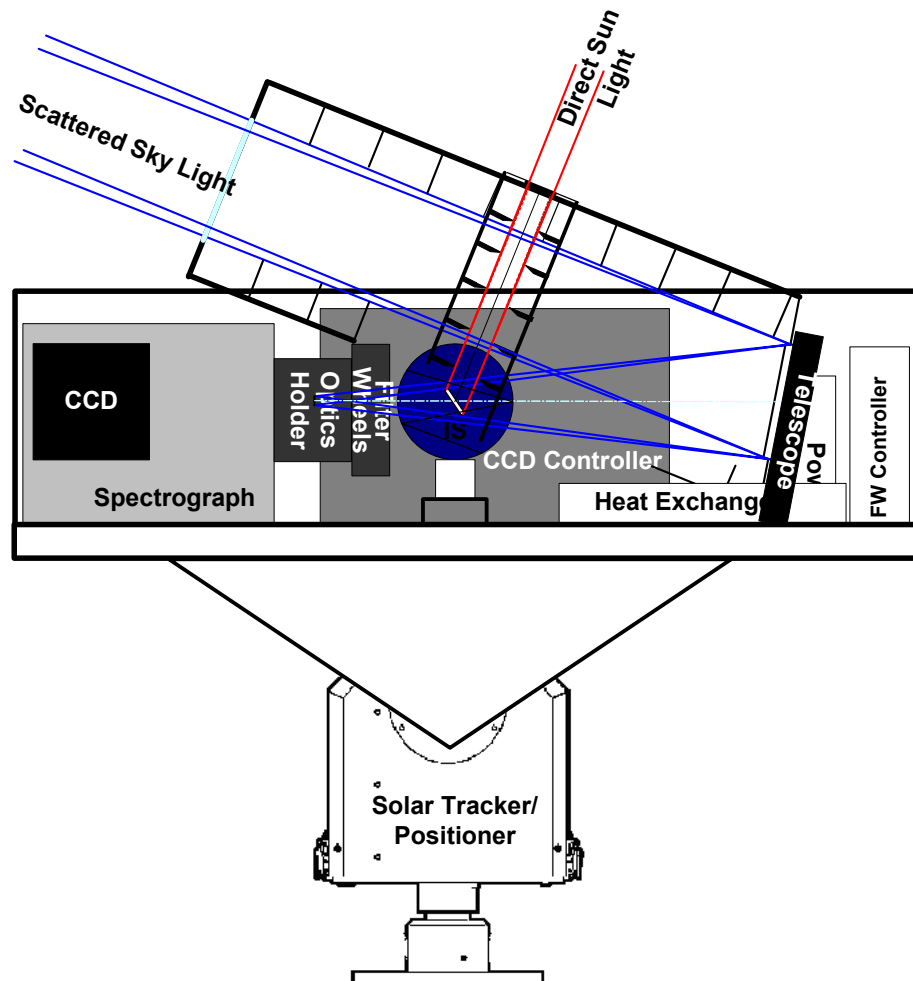
9. Conclusions

The MFOAS instrument is unique in its ability to take both scattered sky measurements and direct sun measurements. This combination allows measurement of air pollution with simple AMFs from the direct sun and also makes use of the MAXDOAS azimuth/elevation technique coupled with a spherical radiative transfer code to derive spatial and full day temporal dependence of urban pollutants. The tropospheric NO_2 pollution trends are captured by the MFOAS instrument as confirmed by in-situ measurements. Preliminary intercomparison with OMI NO_2 tropospheric column densities show reasonable correlation, but require further investigation.

10. Future work

Acknowledgment

Figure 1.
Schematic of the MFDOAS



4a. Location

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Richland is located in a semi-rural area known as Tri-Cities (merged cities of Kennewick, Pasco and Richland, WA) with total population of approximately 150,000 in an area of 250 km². PNNL is situated north from the center of Richland (approximately 15 km) and north-west of the population center.

The major source of local NO₂ pollution is vehicular exhaust.



Figure 3. MFDOAS NO₂ Differential Slant Column: 9 May 2006

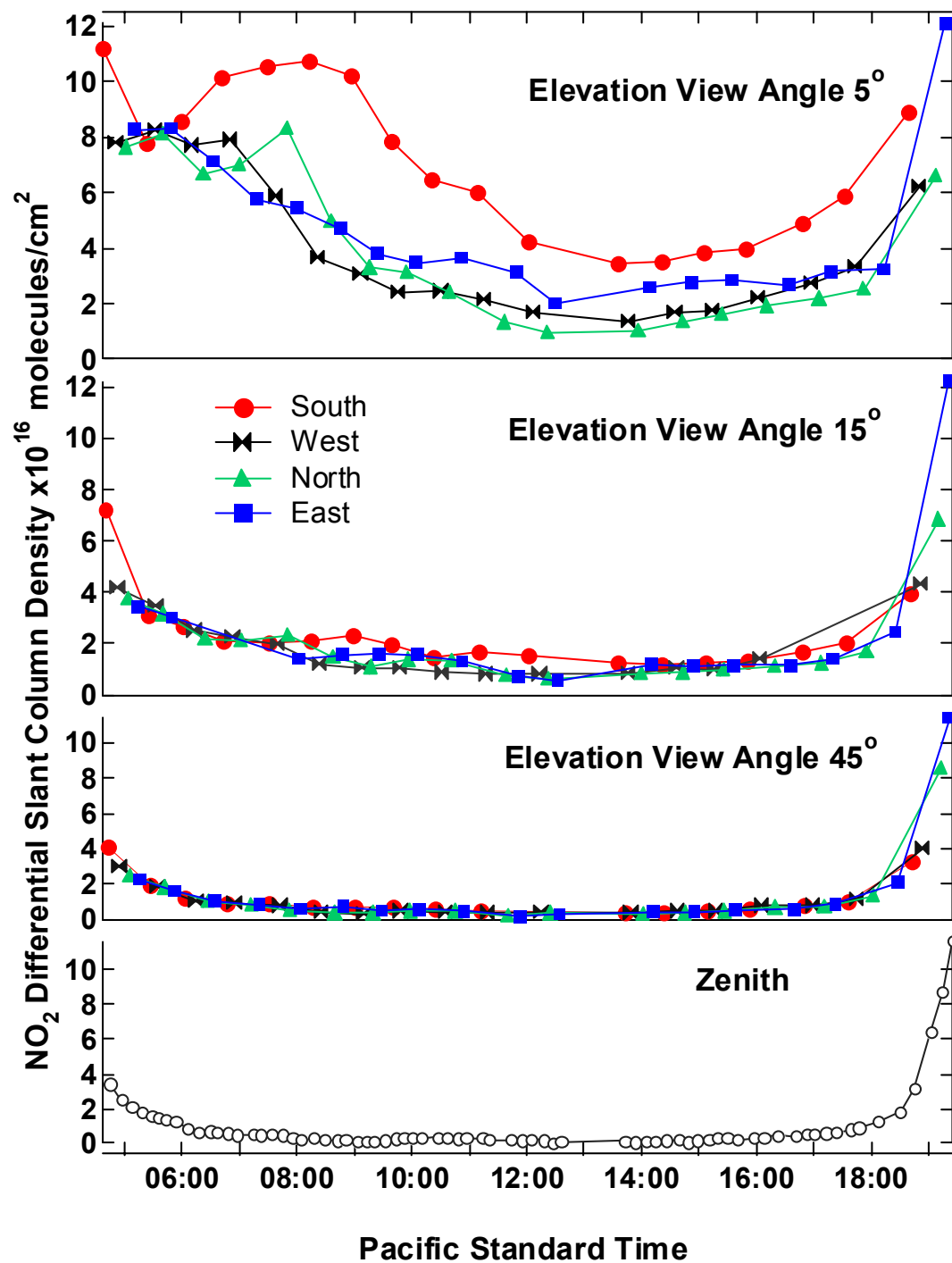


Figure 4. Comparison of NO₂ Tropospheric Δ SCD with CO In-Situ Measurements

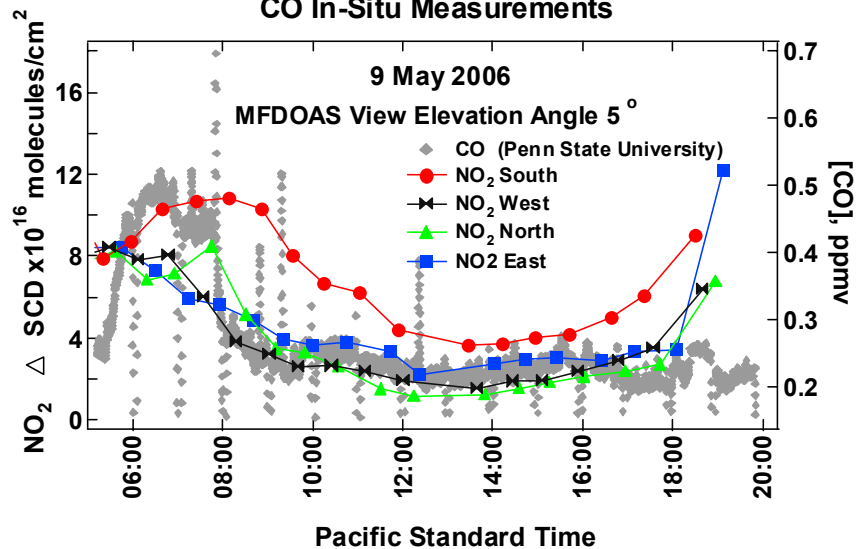


Figure 5. Comparison of NO₂ Tropospheric Δ SCD with CO In-Situ Measurements

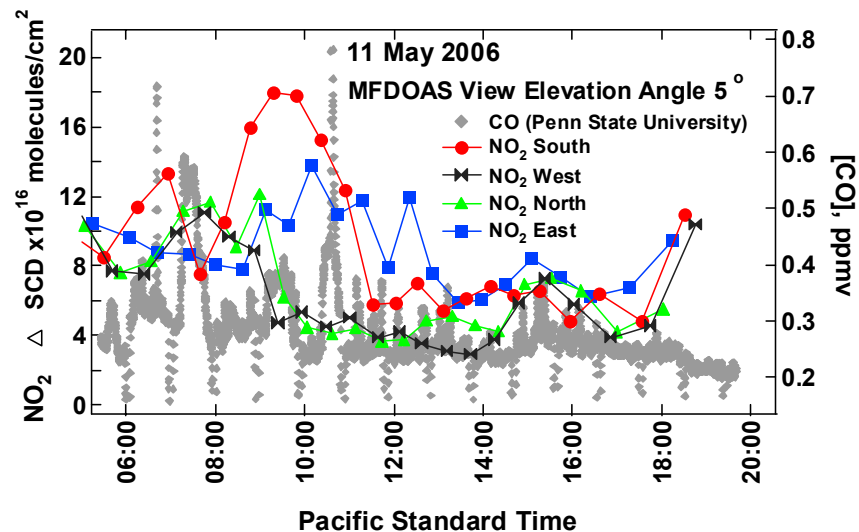
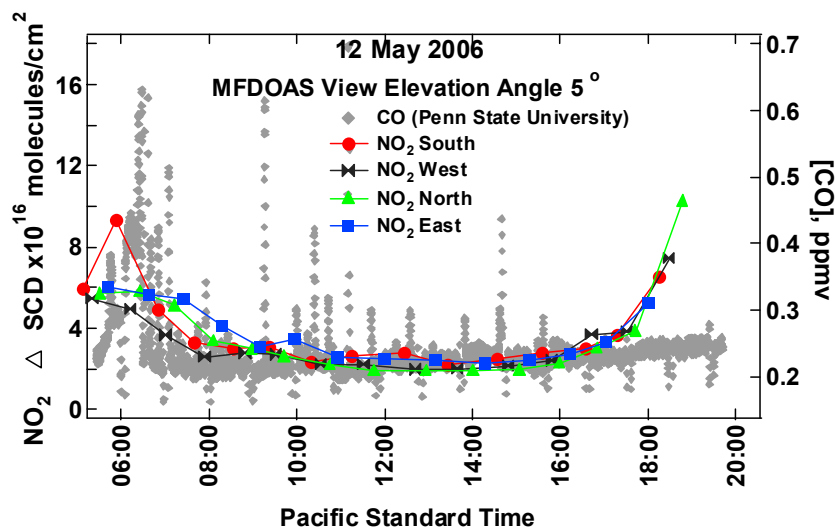


Figure 6. Comparison of NO₂ Tropospheric Δ SCD with CO In-Situ Measurements



**Figure 7. OMI Tropospheric NO₂ Vertical Column Density:
9 May 2006**

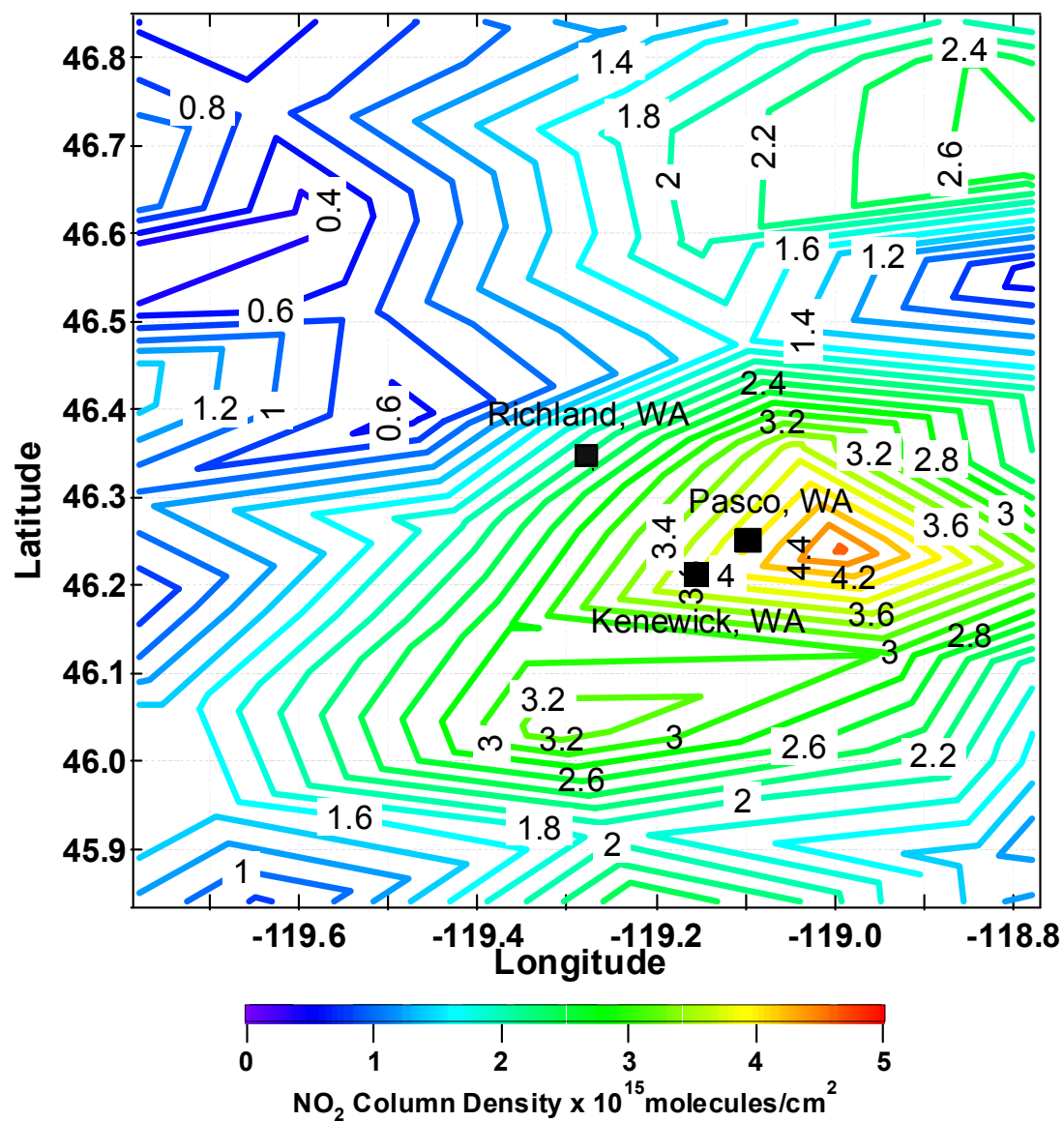


Figure 8. Comparison of OMI Tropospheric NO₂ Vertical Column with MFDOAS NO₂ Differential Slant Column Density

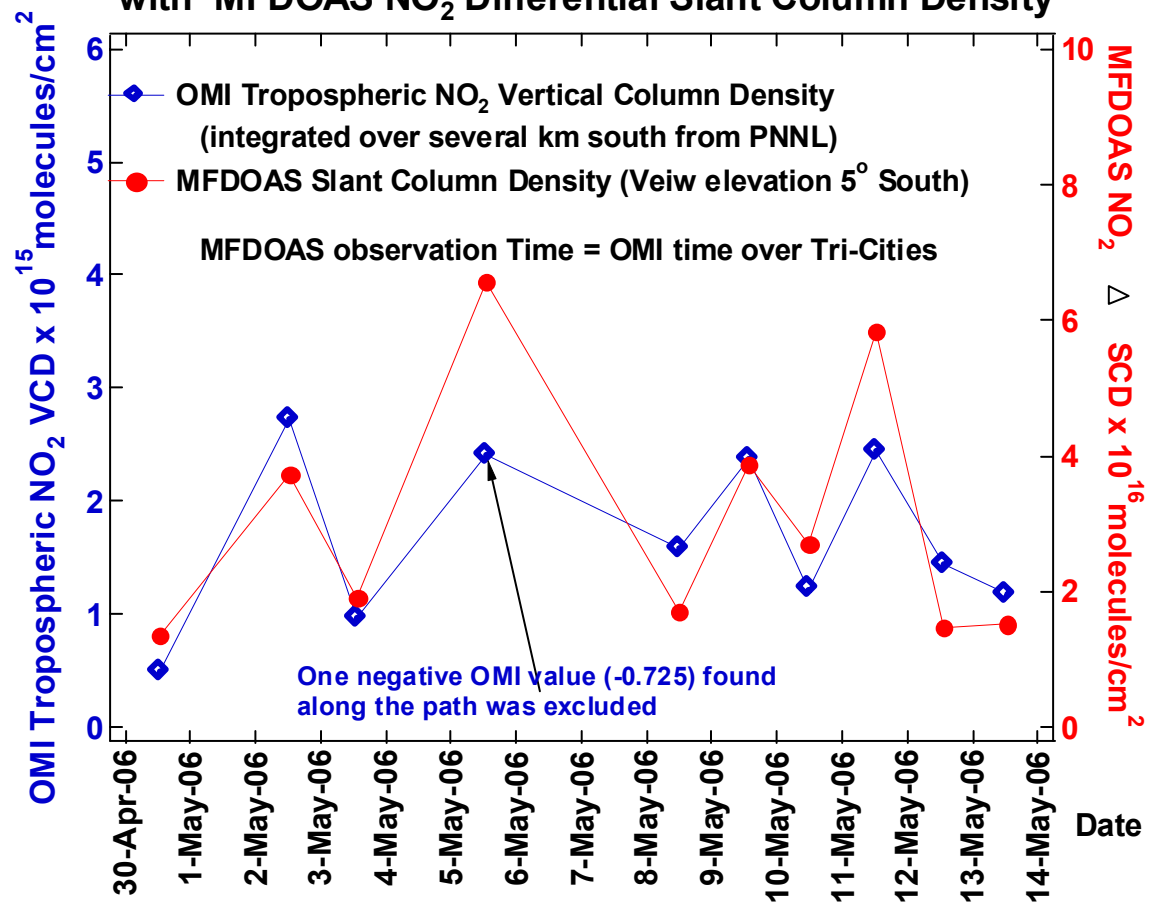
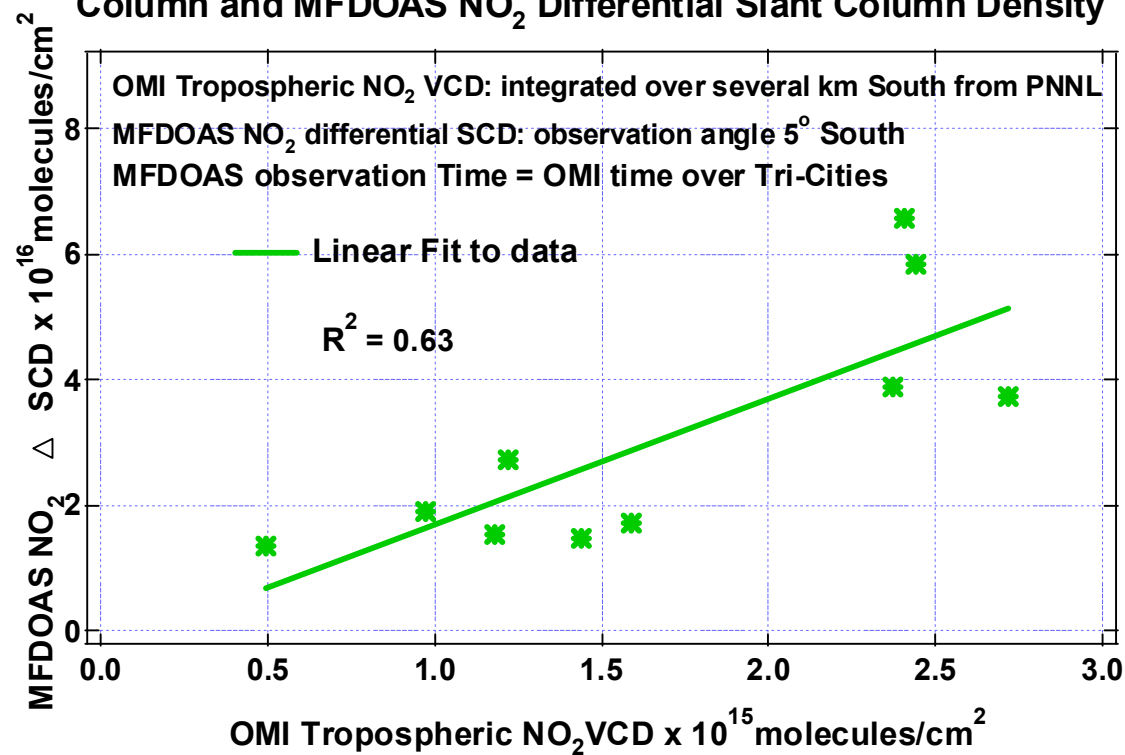


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10. Future work

- Reduction of the differential slant column abundances to vertical tropospheric columns for direct comparison with OMI for both NO₂ and ozone, and use of the new instrument in future field campaigns
- Direct sun measurements will be conducted during fall 2006 in combination with the scattered sky measurements in Washington state
- Intercomparisons at Goddard Space Flight Center and at Table Mountain Observatory (JPL) will be conducted in the spring/summer time frame.